Bathymetric Survey of John Redmond Reservoir, Coffey County, Kansas

Kansas Biological Survey
Applied Science and Technology for Reservoir Assessment (ASTRA)
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SUMMARY

During March and April 2007, the Kansas Biological Survey (KBS) performed a bathymetric survey of John Redmond Reservoir in Coffey County, Kansas. The survey was carried out using acoustic echosounding apparatus linked to a global positioning system. The bathymetric survey was georeferenced to both horizontal and vertical reference datums, allowing the 2007 lake depth data to be compared to a 1957 US Army Corps of Engineers pre-impoundment topographic map for an estimate of sediment accumulation. Five sediment samples were taken from the lake on July 31, 2007, and analyzed for particle size distributions.
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LAKE HISTORY AND PERTINENT INFORMATION

(This section summarized from US Army Corps of Engineers website descriptions)

http://www.swt.usace.army.mil/recreat/ViewHistoryMessage.cfm?tblMessages__LakeName=John%20Redmond%20Reservoir


Location: On the Grand (Neosho) River at river mile 343.7, about 3 miles north-west of Burlington in Coffey County, Kansas (Figure 1).

Purpose: Flood control, water supply, water quality, recreation and wildlife objectives.

History of Construction: Designed and built by the Tulsa District Corps of Engineers at a cost of $29,264,000, construction of the project began in June 1959. The town of Strawn was relocated six miles eastward on higher ground when the dam was constructed. The old town site is now under water. Closure of the embankment was completed in September 1963. The project was completed for full flood control operation in September 1964. All major construction was completed in December 1965. Ultimate development was initiated January 1, 1976 and the conservation pool elevation changed from 1036.0 to 1039.0

In 1958, Congress renamed it John Redmond Dam and Reservoir for the Burlington Daily Republican's publisher, John Redmond. The Neosho Valley was flooded 57 times in 34 years, with the worst flood coming in 1951, one year after Congress authorized the project. Floodwaters ran 30 feet deep at the damsite and one-third million acres were under water.

Type of Structure: The project consists of an earthfill embankment and a gated ogee weir, concrete spillway located in the left abutment. The dam rises to a maximum height of 86.5 feet above the streambed. The structure is 21,790 feet long which includes the lengths of the following components: earthfill embankment, 20,740 feet; concrete spillway including piers and abutments, 664 feet; and two concrete non-overflow bulkhead sections. A road, 24 feet wide, is provided along the crest of the dam.

Spillway & Outlet Works: The spillway is a gated, concrete, ogee weir located in the left abutment. The net opening of the structure is 560 feet and it is equipped with fourteen 40- by 35-foot-high tainter gates. Spillway capacity at the maximum pool (elevation 1074.5) is 578,000 cfs and at the top of the flood control pool (elevation 1068.0) is 428,000 cfs. Two 24-inch- diameter low-flow pipes are located through the left non-overflow section with a discharge capacity of 130 cfs at the spillway crest. A 30-inch-diameter water supply connection is provided for future use. Bank-full capacity of the channel below the dam site is 12,000 cfs.
Figure 1. Location of John Redmond Reservoir in Coffey County, Kansas.
BATHYMETRIC SURVEYING PROCEDURES

Equipment:
KBS runs a Biosonics DT-X acoustic echosounding system (www.biosonicsinc.com) with a 200 kHz split-beam transducer and a 38-kHz single-beam transducer. Latitude-longitude information is provided by a JRC global positioning system (GPS) that interfaces with the Biosonics system. ESRI’s ArcGIS is used for on-lake navigation and positioning, with GPS data feeds provided by the Biosonics unit through a serial cable. Power is provided to the echosounding unit, command/navigation computer, and auxiliary monitor by means of a Yamaha generator.

Pre-survey preparation:
Prior to conducting the survey, geospatial data of the target lake is acquired, including georeferenced National Agricultural Imagery Project (NAIP) photography. The lake boundary was digitized as a polygon shapefile from the 2006 FSA NAIP georeferenced aerial photography obtained online from the Data Access and Service Center (DASC) at the Kansas Geological Survey. The acquisition date of the 2006 NAIP photography was September 24, 2006; the lake surface elevation on that date was 1038.44 feet (316.51 meters) (US Army Corps of Engineers, http://www.swt-wc.usace.army.mil/JOHN.lakepage.html). This lake elevation value was entered as an attribute of the lake perimeter polygon shapefile.

Establishment of lake level on survey dates: Lake levels on the three survey dates were obtained from the US Army Corps of Engineers on the morning of each survey:

<table>
<thead>
<tr>
<th>Date</th>
<th>Elevations (feet)</th>
<th>Elevations (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 19, 2007</td>
<td>1039.65</td>
<td>316.88</td>
</tr>
<tr>
<td>March 28, 2007</td>
<td>1039.89</td>
<td>316.96</td>
</tr>
<tr>
<td>April 2, 2007</td>
<td>1042.01</td>
<td>317.60</td>
</tr>
</tbody>
</table>

Calibration (Temperature and ball check): After boat launch and initialization of the Biosonics system and command computer, system parameters are set in the Biosonics Visual Acquisition software. The temperature of the lake at 1-2 meters was taken with a research-grade Clinefinder metric electronic thermometer. This temperature, in degrees Celsius, is input to the Biosonics Visual Acquisition software to calculate the speed of sound in water at the given temperature at the given depth. Start range, end range, ping duration, and ping interval are also set at this time.

A ball check is performed using a tungsten-carbide sphere supplied by Biosonics for this purpose with each transducer. The ball is lowered to a known distance below the transducer face. The position of the ball in the water column (distance from the transducer face to the ball) is clearly visible on the echogram. The echogram distance is compared to the known distance to assure that parameters are properly set and the system is operating correctly. Ball checks were also performed any time the system was stopped and restarted.
Survey procedures:

Transect lines spaced 150 meters apart were followed (Figure 2). Using the GPS Extension of ArcGIS, the GPS data feed from the GPS receiver via the Biosonics echosounder, and the pre-planned transect pattern, the location of the boat on the lake in real-time is shown on the command/navigation computer screen. To assist the boat operator in navigation, an auxiliary LCD monitor is connected to the computer and placed within the easy view of the boat operator. Transducer face depth on all dates was 0.5 meters below the water surface. Wind and wave conditions on March 28 and April 2 forced the transect pattern to be changed from the cross-sectional, dam-parallel pattern followed on March 19. The 150-meter spacing was maintained, however, modified only by obstructions in the lake (e.g., partially submerged trees) or shallow water and mudflats. Data are automatically logged in new files every half-hour (approximately 9000-ping files) by the Biosonics system. Fifty-two (52) data files were acquired during the three-day survey, comprised of 313,000 raw depth measurements totaling over 1.5 gigabytes of raw data.

Post-processing (Visual Bottom Typer)

The Biosonics DT-X system produces data files in a proprietary DT4 file format containing acoustic and GPS data. To extract the bottom position from the acoustic data, each DT4 file is processed through the Biosonics Visual Bottom Typer (VBT) software. The processing algorithm is described as follows:

"The BioSonics, Inc. bottom tracker is an “end_up” algorithm, in that it begins searching for the bottom echo portion of a ping from the last sample toward the first sample. The bottom tracker tracks the bottom echo by isolating the region(s) where the data exceeds a peak threshold for N consecutive samples, then drops below a surface threshold for M samples. Once a bottom echo has been identified, a bottom sampling window is used to find the next echo. The bottom echo is first isolated by user_defined threshold values that indicate (1) the lowest energy to include in the bottom echo (bottom detection threshold) and (2) the lowest energy to start looking for a bottom peak (peak threshold). The bottom detection threshold allows the user to filter out noise caused by a low data acquisition threshold. The peak threshold prevents the algorithm from identifying the small energy echoes (due to fish, sediment or plant life) as a bottom echo." (Biosonics Visual Bottom Typer User's Manual, Version 1.10, p. 70).

Data is output as a comma-delimited (*.csv) text file. A set number of qualifying pings are averaged to produce a single report (for example, the output for ping 31 {when pings per report is 20} is the average of all values for pings 12-31).
Figure 2. Bathymetric survey transects during the three survey days.
Post-processing (ArcGIS):

Ingest to ArcGIS is accomplished by using the **Tools – Add XY Data** option. The projection information is specified at this time (WGS84). Files are displayed as Event files, and can be exported as shapefiles if desired. Typically, Event files are merged using the ArcGIS command **Data Management Tools – General – Merge**, and the output from this is a shapefile.

Initial QA/QC is performed next. The point shapefile(s) is visually evaluated for any points with spurious lat/lon coordinates, which should be obvious (and unlikely). The attribute table is examined for any points reporting a value of 0 in the depth file, and these points are deleted. Any points with a value less than the start range of the data acquisition parameter (for the John Redmond surveys, this value was 0.5 meters) is also deleted.

In the attribute table, the adjustment for transducer depth is performed next. A new field – **AdjDepth** – is added to the attribute table of the point shapefile. The value for **AdjDepth** is calculated as \( \text{AdjDepth} = \text{Depth} + (\text{Transducer Face Depth}) \), where the Transducer Face Depth represents the depth of the transducer face below water level in meters (for the John Redmond surveys, this value was also 0.5 meters).

To set depths relative to lake elevation, another field is added to the attribute table of the point shapefile, **Depth_Elev**. The value for this attribute is then computed as \( \text{Depth_Elev} = (\text{Elevation of the Water Surface}) - \text{Adj_Depth} \). The lake surface elevation for each survey date was used for each data set collected on that date. Thus, all depth measurements are expressed as the elevation of the lake **bottom**, which then allowed all three survey days of data to be combined into a master data file for the entire lake.

A triangulated irregular network (TIN) was created using the master depth data point shapefile and the lake polygon shapefile with the lake surface elevation. Output projection is typically specified to be the same as the input data. Raster interpolation of the point data is also performed using the same input data and the **Topo to Raster** option within the 3D Extension of ArcGIS. Following creation of the TIN file and the raster file, any necessary projections or conversions from meters to feet units are performed (Figure 3).
Figure 3. Lake depth map of John Redmond Reservoir based on 2007 bathymetric survey.

Depth based on water surface elevation of 1038.55 AMSL.

Line contour interval is 2 feet.
SEDIMENT SAMPLING PROCEDURES

KBS operates a Specialty Devices Inc. sediment vibracorer mounted on a dedicated 24’ pontoon boat (Figure 4). The vibracorer uses 3” diameter aluminum thinwall pipe in user-specified lengths (KBS has used up to 10’ sections). The vibracorer runs off 24-volt batteries, and uses an electric motor with counter-rotating weights in the vibracorer head unit to create a high-frequency vibration in the pipe, allowing the pipe to penetrate even solidly packed sediments and substrate as it is lowered into the lake using a manually operated winch system. Once the open end of the core pipe has penetrated to the substrate, the unit is turned off and the unit is raised to the surface using the winch. At the surface, the pipe containing the sediment core is disconnected from the vibracore head for further onboard processing. The sediment core can be cut into sections while in the pipe, the pipe bisected longitudinally for taking samples along the length of the core, or the sediment can be manually extruded from the pipe and measured.

Specifications from the Kansas Water Office, relayed from the US Army Corps of Engineers Tulsa District, requested that KBS acquire five (5) cores spaced along the reservoir thalweg from the dam to the upper end of the impoundment be collected, the sediment thickness measured, and the top 6 inches (0.5 foot) of each sediment core be saved for particle size analysis.

Core sampling on John Redmond Reservoir was conducted on July 31, 2007. At each site, determined using GPS, the core boat was anchored and the vibracore system used to extract a sediment core down to and including the upper several inches of pre-impoundment soil (substrate). Cores were extruded horizontally and the amount of sediment accumulation measured (from top of substrate to top of sediment core). The location of each core site was recorded using the GPS in UTM coordinates (NAD83, UTM Zone 15N) (Figure 5). Five cores were taken and six samples of the top six inches of sediment were collected for particle size analysis. The top six inches of core #JR-01, closest to the dam, appeared unexpectedly sandy, given its location in the reservoir, and the next six inches (core inches 6-12, core #JR-01a)) were collected as well for particle size analysis. Sediment samples were sealed, labeled, and sent to Midwest Laboratories, Inc., of Omaha, Nebraska for particle size analysis (ASTM D422).
Figure 5. Location of core samples within John Redmond Reservoir, July 31, 2007.
PRE-IMPOUNDMENT MAP

Caution should be exercised in drawing conclusions based on comparison between two maps of different scales, dates, and production methods.

A pre-impoundment topographic map dated 1957 with a contour interval of five feet (5') was obtained in digital form from the Corps of Engineers Tulsa District Office via the Kansas Water Office (Figure 6). The map was converted from PDF format to TIF format at 300 dpi and georeferenced to the Universal Transverse Mercator (UTM) projection, NAD83, Zone 15, in ERDAS Imagine image processing software. A total of fifty (50) control points were located on the 1957 Corps map at section corners and referenced to corresponding locations on a UTM-georeferenced USGS Digital Raster Graphic (DRG) topographic map. A second-order polynomial transformation was computed from the 50 coordinate pairs and the 1957 map was resampled to the UTM coordinate system using a nearest-neighbor algorithm with an output pixel size of three (3) meters.

Contour lines were manually digitized to a polyline shapefile and attributed. Per the direction of the Kansas Water Office, all contour intervals at elevations 1050 feet and below were digitized (every five feet of vertical); above the 1050-foot elevation, every other contour interval was digitized (every ten feet of vertical). Lines representing streams were digitized as a separate polyline shapefile, and spot locations of elevation appearing on the map (benchmarks and high water marks) were digitized as a point shapefile (Figure 7).

The contour line file, the stream line file, and the spot elevation point file were input to the TIN tool in ArcGIS. The TIN tool uses the contour line file and the spot elevation file to establish elevations within a triangulated irregular network, while the stream line file is used as a breakline to “force” valley bottoms to their “true” locations. The TIN file was then converted to a raster file to facilitate comparison of elevations with the 2007 bathymetric data (present-day lake bottom elevations) (Figure 8).

Changes in lake bottom elevation between 1957 and 2007 were computed by digitally subtracting the 1957 digital elevation model from the 2007 digital elevation model. Negative numbers on the resulting output indicate loss of material during the 50-year period; positive numbers indicate accumulated material (siltation) (Figure 9). The difference map suggests that the greatest sedimentation has occurred in the former river channel, as might be expected; furthermore, the majority of the non-river channel silt accumulation has occurred in the lower part of the reservoir (Figure 9; orange and yellow colors). Some loss of material has occurred in the 50-year period, principally along the northern lake shore (possible shoreline erosion) and just offshore of the park at the north end of the dam (possible material removal during construction) (Figure 9).
Figure 6. Scanned original 1957 pre-impoundment contour map of John Redmond Reservoir area.
Figure 7. Contour lines, benchmarks, and streamlines digitized from 1957 map.
Figure 8. Digital elevation model derived from 1957 pre-impoundment contour map.
Figure 9. Elevation difference map between 2007 bathymetric survey and 1957 Corps of Engineers topographic map. Negative numbers indicate loss of material during the 50-year period; positive numbers indicate accumulated material (siltation).
Sediment thickness comparison

Change in reservoir volume, 1957-2007: Reservoir volume at 316.5 meters above sea level was computed for both the 1957 and the 2007 maps within the perimeter of the lake as digitized from the 2006 NAIP photography.

<table>
<thead>
<tr>
<th></th>
<th>Volume (m³)</th>
<th>Volume (acre-feet)</th>
</tr>
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<tbody>
<tr>
<td>1957</td>
<td>90,822,647</td>
<td>73,566</td>
</tr>
<tr>
<td>2007</td>
<td>57,177,966</td>
<td>46,314</td>
</tr>
<tr>
<td>Difference (value)</td>
<td>33,644,681</td>
<td>27,252</td>
</tr>
<tr>
<td>Difference (%)</td>
<td>0.63, or current capacity is 63% of 1957 capacity</td>
<td></td>
</tr>
</tbody>
</table>

Comparison between sediment thickness at core locations and difference map: Locations of the five sediment cores taken July 2007 were plotted on the 1957-2007 difference map and the map-predicted sediment thickness were extracted.

Figure 10. Comparison of sediment thicknesses predicted by map differencing versus sediment coring.
**BATHYMETRIC SURVEY RESULTS**

**Area-Volume-Elevation Tables:**
Area-volume-elevation tables were computed for the impoundment for all elevations falling below the water surface on the date of the bathymetric mapping (Table 1, Table 2). By convention, units are expressed in acres, feet, and acre-feet, rather than the metric units in which the data were acquired.

<table>
<thead>
<tr>
<th>Elevation (ft NGVD)</th>
<th>0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
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<th>0.7</th>
<th>0.8</th>
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Table 2
Cumulative volume in acre-feet by tenth foot elevation increments

<table>
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<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
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<td>47284</td>
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</table>
Charts of cumulative area as a function of elevation and cumulative volume as a function of elevation were also produced (Figures 10, 11):

**Figure 11.** Graph of cumulative area by elevation.

**Figure 12.** Graph of cumulative volume by elevation.
Acoustic Estimation Of Sediment Thickness

The acoustical approach uses high-frequency and low-frequency transducers (200-kHz and 38-kHz) operated simultaneously during a lake survey. A review of the relevant literature indicates that differencing the acoustic returns from the high and low frequencies (reflecting off the current reservoir bottom and the pre-impoundment bottom, respectively) has shown considerable promise for successful sediment thickness mapping in inland reservoirs (esp. the work by Dunbar et al., Baylor University) (Figure 6). Dunbar et al further noted:

Our results indicate that mapping the base of sediment acoustically works best in reservoirs that are dominated by fine-grained deposition (clay and silt, rather than silt and sand). Reservoirs with fined-grained-deposition fill from the dam towards the backwater and no delta forms at the tributary inlet. As long as the water depth is greater than the sediment thickness, the base of sediment can be mapped without interference from the water-bottom multiple reflection and the entire reservoir can be surveyed from a boat. Coarse-grained dominated reservoirs fill from the backwater towards the dam and form deltas in the backwater. In the time the backwater region cannot be surveyed, because it is dry land. In these cases, the only option is differing the bathymetry.

Figure 13. Echograms of acoustic reflectance at multiple frequencies for reservoir sediments: a) High frequency, showing strong discrimination of sediment-water interface; b) and c) Increasing penetration of post-impoundment sediments and increasing return from pre-impoundment substrate with progressively lower frequencies. Abridged figure from John A. Dunbar, J.A., Allen, P.M. and Higley, P.D. 2000. Color-encoding multifrequency acoustic data for near-bottom studies. *Geophysics* 65, 994.
With funding from the Kansas Water Office, the Kansas Biological Survey purchased a 38-kHz transducer from Biosonics Inc to be operated simultaneously with the existing 200-kHz transducer. The two transducers (200-kHz and 38-kHz) were deployed on John Redmond Reservoir by KBS during the March-April bathymetric mapping survey. Examination of the echograms suggests that in this case, for this particular reservoir, no discernible bottom penetration was achieved by the 38-kHz transducer on this reservoir (Figure 14).

Figure 14. Echograms of acoustic data from John Redmond Reservoir.  
*Top*: 200-kHz echogram; *Bottom*: 38-kHz echogram.
SEDIMENT SAMPLING RESULTS

Original detailed sediment sample analysis reports for each sample follow this page.

### Table 3
John Redmond Reservoir Sediment Particle Size Analysis

<table>
<thead>
<tr>
<th>Site</th>
<th>MW Labs Sample No.</th>
<th>%Cobbles</th>
<th>%Crs Gravel</th>
<th>%Fine Gravel</th>
<th>%Crs Sand</th>
<th>%Med. Sand</th>
<th>%Fine Sand</th>
<th>%All Sand</th>
<th>%Silt</th>
<th>%Clay</th>
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<td>0.4</td>
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Figure 15. John Redmond Reservoir sediment particle size analysis.